

AMENDMENTS TO THE SPECIFICATION

Please replace paragraph [0032] with the following amended paragraph:

[0032] A vacuum pump 18 [[is]] and the conduit system 46A are used to evacuate the process chamber 10 and to maintain the pressure inside the process chamber 10. A gas manifold 34, through which process gases are introduced into the process chamber 10, is located above the substrate support pedestal 48. The gas manifold 34 is connected to a gas panel (not shown), which controls and supplies various process gases to the process chamber 10.

Please replace paragraph [0034] with the following amended paragraph:

[0034] The gas manifold 34 includes a plurality of electronic control valves (not shown). The electronic control valves as used herein refer to any control valve capable of providing rapid and precise gas flow to the process chamber 10 with valve open and close cycles within a range from about 0.01 seconds to about 10 seconds, preferably from about 0.05 seconds to about 2 seconds and more preferably from about 0.1 seconds to about 1 second.

Please replace paragraph [0037] with the following amended paragraph:

[0037] Figure 2 is a schematic cross-sectional view of one embodiment of a process chamber 80 including a gas delivery apparatus 130 adapted for cyclic deposition, such as atomic layer deposition or rapid chemical vapor deposition. A detailed description for a process chamber 80 is described in commonly assigned United States Patent Application Publication No. 20030079686, and issued as U.S. Patent No. 6,916,398, and commonly assigned United States Patent Application Serial No. 10/281,079, entitled "Gas Delivery Apparatus for Atomic Layer Deposition", filed October 25, 2002, and published as U.S. Pub. No. 2003-0121608, which are both incorporated herein in their entirety by reference. The terms atomic layer deposition (ALD) and rapid chemical

vapor deposition as used herein refer to the sequential introduction of reactants to deposit a thin layer over a substrate structure. The sequential introduction of reactants may be repeated to deposit a plurality of thin layers to form a conformal layer to a desired thickness. The process chamber 80 may also be adapted for other deposition techniques.

Please replace paragraphs [0044]-[0048] with the following amended paragraphs:

[0044] In one embodiment, the gas delivery apparatus 130 comprises a chamber lid 132. The chamber lid 132 includes an expanding channel 134 extending from a central portion of the chamber lid 132 and a bottom surface 160 extending from the expanding channel 134 to a peripheral portion of the chamber lid 132. The bottom surface 160 is sized and shaped to substantially cover a substrate 90 disposed on the substrate support 92. The expanding channel 134 has gas inlets 136A, 136B to provide gas flows from two similar pairs of valves 142A/152A, 142B/152B, which [[. The gas flows from the valves 142A, 142B]] may be provided together and/or separately.

[0045] In one configuration, valve 142A and valve 142B are coupled to separate reactant gas sources but are preferably coupled to the same purge gas source. For example, valve 142A is coupled to reactant gas source 138 and valve 142B is coupled to reactant gas source 139, and both valves 142A, 142B are coupled to purge gas source 140. Each valve 142A, 142B includes a delivery line 143A, 143B having a valve seat assembly 144A, 144B and each valves 152A, 152B includes a purge line 145A, 145B having a valve seat assembly 146A, 146B. The delivery line 143A, 143B is in communication with the reactant gas source 138, 139 and is in communication with the gas inlet 136A, 136B of the expanding channel 134. The valve seat assembly 144A, 144B of the delivery line 143A, 143B controls the flow of the reactant gas from the reactant gas source 138, 139 to the expanding channel 134. The purge line 145A, 145B is in communication with the purge gas source 140 and intersects the delivery lines 143A, 143B downstream of the valve seat assembly 144A, 144B of the delivery

line 143A, 143B valves 142A, 142B. The valve seat assembly 146A, 146B of the purge line 145A, 145B controls the flow of the purge gas from the purge gas source 140 to the delivery line 143A, 143B. If a carrier gas is used to deliver reactant gases from the reactant gas source 138, 139, preferably the same gas is used as a carrier gas and a purge gas (*i.e.*, an argon gas used as a carrier gas and a purge gas).

[0046] Each valve seat assembly 144A, 144B, 146A, 146B may comprise a diaphragm and a valve seat. The diaphragm may be biased open or closed and may be actuated closed or open respectively. The diaphragms may be pneumatically actuated or may be electrically actuated. Examples of pneumatically actuated valves include pneumatically actuated valves available from Fujiken and Veriflow. Examples of electrically actuated valves include electrically actuated valves available from Fujiken. Programmable logic controllers 148A, 148B may be coupled to the valves 142A, 142B to control actuation of the diaphragms of the valve seat assemblies 144A, 144B, 146A, 146B of the valves 142A, 142B. Pneumatically actuated valves may provide pulses of gases in time periods as low as about 0.020 seconds. Electrically actuated valves may provide pulses of gases in time periods as low as about 0.005 seconds. An electrically actuated valve typically requires the use of a driver coupled between the valve and the programmable logic controller.

[0047] Each valve 142A, 142B may be a zero dead volume valve to enable flushing of a reactant gas from the delivery line 143A, 143B when the valve seat assembly 144A, 144B of the valve is closed. For example, the purge line 145A, 145B may be positioned adjacent the valve seat assembly 144A, 144B of the delivery line 143A, 143B. When the valve seat assembly 144A, 144B is closed, the purge line 145A, 145B may provide a purge gas to flush the delivery line 143A, 143B. In the embodiment shown, the purge line 145A, 145B is positioned slightly spaced from the valve seat assembly 144A, 144B of the delivery line 143A, 143B so that a purge gas is not directly delivered into the valve seat assembly 144A, 144B when open. A zero dead volume valve as used herein is defined as a valve which has negligible dead volume (*i.e.*, not necessarily zero dead volume). [[.]])

[0048] Each valve pair 142A/152A, 142B/152B may be adapted to provide a combined gas flow and/or separate gas flows of the reactant gas 138, 139 and the purge gas 140. In reference to valve pair 142A/152A, one example of a combined gas flow of the reactant gas 138 and the purge gas 140 provided by valve 142A comprises a continuous flow of a purge gas from the purge gas source 140 through purge line 145A and pulses of a reactant gas from the reactant gas source 138 through delivery line 143A. The continuous flow of the purge gas may be provided by leaving diaphragm of the valve seat assembly 146A of the purge line 145A open. The pulses of the reactant gas from the reactant gas source 138 may be provided by opening and closing the diaphragm of the valve seat 144A of the delivery line 143A. In reference to valve pair 142A/152A, one example of separate gas flows of the reactant gas 138 and the purge gas 140 provided by valve 142A comprises pulses of a purge gas from the purge gas source 140 through purge line 145A and pulses of a reactant gas from the reactant gas source 138 through delivery line 143A. The pulses of the purge gas may be provided by opening and closing the diaphragm of the valve seat assembly 146A of the purge line 145A open. The pulses of the reactant gas from the reactant gas source 138 may be provided by opening and closing the diaphragm valve seat 144A of the delivery line 143A.

Please replace paragraph [0050] with the following amended paragraph:

[0050] In Figure 2, the expanding channel 134 comprises a channel which has an inner diameter which increases from an upper portion 137 of cap 172 to a lower portion 135 of the expanding channel 134 adjacent the bottom surface 160 of the chamber lid 132.

Please replace paragraph [0054] with the following amended paragraph:

[0054] Not wishing to be bound by theory, it is believed that the diameter of the expanding channel 134, which is gradually increasing from the upper portion 137 to the

lower portion 135 of the expanding channel, allows less of an adiabatic expansion of a gas through the expanding channel 134 which helps to control the temperature of the gas. For instance, a sudden adiabatic expansion of a gas delivered through the gas inlet 136A, 136B into the expanding channel 134 may result in a drop in the temperature of the gas which may cause condensation of the precursor vapor and formation of particles. On the other hand, a gradually expanding channel 134 according to embodiments of the present invention is believed to provide less of an adiabatic expansion of a gas. Therefore, more heat may be transferred to or from the gas, and, thus, the temperature of the gas may be more easily controlled by controlling the surrounding temperature of the gas (*i.e.*, controlling the temperature of the chamber lid 132). The gradually expanding channel may comprise one or more tapered inner surfaces, such as a tapered straight surface, a concave surface, a convex surface, or combinations thereof or may comprise sections of one or more tapered inner surfaces (*i.e.*, a portion tapered, such as bottom surface 160 and a portion non-tapered, such as choke 162).

Please replace paragraph [0057] with the following amended paragraph:

[0057] The control unit 180 may be one of any form of general purpose computer processor that can be used in an industrial setting for controlling various chambers and sub-processors. The CPU 182 may use any suitable memory 186, such as random access memory, read only memory, floppy disk drive, compact disc drive, hard disk, or any other form of digital storage, local or remote. Various support circuits may be coupled to the CPU 182 for supporting the process chamber 80. The control unit 180 may be coupled to another controller that is located adjacent individual chamber components, such as the programmable logic controllers 148A, 148B of the valves 142A, 142B. Bi-directional communications between the control unit 180 and various other components of the process chamber 80 are handled through numerous signal cables collectively referred to as signal buses 188, some of which are illustrated in Figure 2. In addition to control of process gases and purge gases from gas sources 138, 139, 140 and from the programmable logic controllers 148A, 148B of the valves

142A, 142B, 152A, 152B, the control unit 180 may be configured to be responsible for automated control of other activities used in wafer processing, such as wafer transport, temperature control, chamber evacuation, among other activities, some of which are described elsewhere herein.

Please replace paragraphs [0061]-[0062] with the following amended paragraphs:

[0061] In one embodiment where a constant carrier gas flow is desired, a carrier gas stream is established within the process chamber as indicated in step 104. Carrier gases may be selected so as to also act as a purge gas for the removal of volatile reactants and/or by-products from the process chamber. Carrier or purge gases such as, for example, helium (He), argon (Ar), nitrogen (N₂), hydrogen (H₂), or and combinations thereof, among others may be used. The pulse of the purge gas lasts for a predetermined time interval, such as within a range from about 0.01 seconds to about 10 seconds, preferably from about 0.07 seconds to about 1 second and more preferably from about 0.1 seconds to about 1 second. The carrier gas and purge gases may be provided at a flow rate between about 500 sccm to about 5,000 sccm, preferably between about 500 sccm to about 2,500 sccm for 200 mm substrates and between about 1,000 sccm to about 5,000 sccm for 300 mm substrates.

[0062] Referring to step 106, after the carrier gas stream is established within the process chamber, a pulse of a ruthenium-containing precursor is added to the carrier gas stream. The term pulse as used herein refers to a dose of material injected into the process chamber or into the carrier gas stream. The pulse of the ruthenium-containing precursor lasts for a predetermined time interval, such as within a range from about 0.01 seconds to about 10 seconds, preferably from about 0.05 seconds to about 4 seconds, for example, about 2 seconds.

Please replace paragraph [0067] with the following amended paragraph:

[0067] In step 108, after the excess ruthenium-containing compound has been flushed from the process chamber by the carrier gas stream, a pulse of a reducing gas or reductant is added to the carrier gas stream. A reducing gas may include a reductant and another gas, such as a carrier gas. The pulse of the reducing gas also lasts for a predetermined time interval. In general, the time interval for the pulse of the reducing gas should be long enough for adsorption of at least a monolayer of the reducing gas on the ruthenium-containing compound. The pulse of reducing gas lasts for a predetermined time interval, such as within a range from about 0.01 seconds to about 10 seconds, preferably from about 0.1 seconds to about 2 seconds and more preferably from about 0.1 seconds to about 1 second. Thereafter, excess reducing gas is flushed from the process chamber by the carrier gas stream.

Please replace paragraph [0082] with the following amended paragraph:

[0082] One exemplary process of depositing a ruthenium layer by an ALD process to a substrate (e.g., 300 mm), in the process chamber 80 of Figure 2, comprises providing pulses of a ruthenium-containing compound, such as $(\text{DMPD})_2\text{Ru}$, from gas source 138 at a flow rate between about 0.01 sccm and about 5 sccm, preferably between about 0.1 sccm and about 1 sccm, through valve 142A for a pulse time of about 4 seconds or less, preferably about 1.5 seconds or less, such as about 0.1 seconds or less, and as low as about 0.05 seconds or less due the smaller volume of the reaction zone 164 (as compared to chamber 8 of Figure 1). Pulses of a reducing gas, such as oxygen (O_2), may be provided from gas source 139 at a flow rate between about 1 sccm and about 1,000 sccm, preferably between 10 sccm and about 500 sccm, more preferably from about 100 sccm to about 300 sccm through valve 142B for a pulse time of about 2 seconds or less, about 1 second or less, or about 0.1 seconds or less due to a smaller volume of the reaction zone 164. An argon purge gas at a flow rate between about 500 sccm and about 5,000 sccm, preferably, between about 1,500 sccm and about 3,500 sccm, may be continuously provided or pulsed from gas source 140 through valves 142A, 142B. The time between pulses of $(\text{DMPD})_2\text{Ru}$ and O_2 may be about 0.5 seconds or less, such as about 0.1 seconds or less, and as low as about 0.07 seconds

or less due to the smaller volume of the reaction zone 164. It is believed to fill a reaction zone with a reactant gas and/or purge gas, pulse times as low as about 0.016 seconds are sufficient, with correspondingly shorter pulse times for a reaction zone 164 sized for smaller wafers (*e.g.*, 200 mm). The heater temperature is maintained from about 100°C to about 600°C, preferably from about 200°C to about 400°C, for example, about 350°C. The chamber pressure is maintained from about 0.1 Torr to about 20 Torr, preferably from about 1.0 Torr to about 10 Torr, for example, at about 1.5 Torr. This process provides a ruthenium layer with a thickness from about 0.1 Å to about 1.0 Å per ALD cycle. The alternating sequence may be repeated until a desired thickness is achieved.

Please replace paragraph [0099] with the following amended paragraph:

[0099] The Ru-ALD experiments were completed in an ALD chamber, as depicted in Figure 2, available from Applied Materials, Inc., Santa Clara, California. Precursor A, a ruthenium-containing compound, is bis(2,4-dimethylpentadienyl)ruthenium ((CH₂CH(CH₃)CHCH(CH₃)CH₂)₂Ru) and Precursor B, a ruthenocene compound, is bis(ethylcyclopentadienyl)ruthenium ((EtCp)₂Ru), as listed in Table 1. During the precursor transfer, the chamber pressure was maintained at less than 5x10⁻⁶ Torr. The chamber spacing (distance between the wafer and the top of chamber body) was 230 mils. An ALD cycle included the following steps. Argon carrier gas containing either Precursor A or Precursor B was exposed to the substrate for 4 seconds at a flow rate of 100 sccm. The chamber was purged with argon for 0.5 seconds at a flow rate of 2,000 sccm and then the substrate was exposed to oxygen (O₂) for 1 second at a flow rate of 200 sccm. For the final step in the cycle, the chamber was purged with argon for 0.5 seconds at a flow rate of 2,000 sccm. The ALD process was yielded after the repetition of 100 cycles.

Please replace paragraph [0103] with the following amended paragraph:

[0103] An ALD cycle included the following steps. Argon carrier gas containing either Precursor A or Precursor B was exposed to the substrate for 4 seconds at a flow rate of 100 sccm. The chamber was purged with argon for 0.5 seconds at a flow rate of 2,000 sccm and then the substrate was exposed to oxygen (O₂) for 1 second at a flow rate of 200 sccm. For the final step in the cycle, the chamber was purged with argon for 0.5 seconds at a flow rate of 2,000 sccm. The ALD process was yielded after the repetition of 120 cycles.